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ESTIMATING THE 1983 POPULATION OF HAWAIIAN MONK SEALS FROM BEACH COUNTS

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**ESTIMATING THE 1983 POPULATION OF
HAWAIIAN MONK SEALS FROM BEACH COUNTS**

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INTRODUCTION

Although numerous counts of Hawaiian monk seal, Monachus schauinslandi, have been made in recent years, an estimate of total population abundance for this endangered species has remained elusive. Fundamentally this is because, although the number of seals hauled out at any particular time can be counted with little error, it is not known what fraction of the total population such beach counts represent. Furthermore, this fraction is probably not constant, but varies with season, age, sex, time of day, weather, and other factors. Beach counts differing in method and completeness of counting have been made over the past 25 years by various researchers (Johnson et al. 1982). Past abundance estimates have had to report beach counts only, it being understood that these counts represented only some unknown fraction of the total population. Recently, as the species has been studied more intensively, attempts have been made to estimate the total abundance. Using several different methods, Johnson and Johnson (1981) estimated the resident population of monk seals on Laysan Island. Wetherall¹ developed several techniques of estimating total abundance based on a stochastic model of the monk seal's annual molting dynamics. Unfortunately, Wetherall's estimators could not be used since they required information not available at the time--namely, the haul-out probabilities of seals of different classes and the probability distributions for time spent in the molt and premolt states.

Since 1980, the Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, has conducted field studies of the Hawaiian monk seal in the Northwestern Hawaiian Islands. On Lisianski Island in 1982 and 1983, researchers were able to identify individually all seals using the island with a combination of natural scar patterns and identifying bleach marks applied for the purpose (Stone 1984; Johanos and Kam²). Therefore, the population of monk seals on this island was completely known, and the fraction of seals that was hauled out on any particular date can be computed exactly from the beach count. Replicated beach counts were also made in 1983 at other islands in the monk seal's range. This allows the possibility of using the known haul-out fraction from Lisianski Island to adjust the beach counts of monk seals on the other Northwestern Hawaiian Islands to arrive at an estimate of total population size over the whole range of the species.

This report is a preliminary attempt to estimate the 1983 population of Hawaiian monk seals by this method. The total population estimate given

¹Wetherall, J. A. 1980. Estimating monk seal populations using change-in-ratio and least squares methods. Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812, Admin. Rep. H-80-2, 22 p.

²Johanos, T. C., and Kam, A. K. H. Monk seal research on Lisianski Island, 1983. Manuscr. in prep. Southwest Fish. Cent., Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812.

here is preliminary and should not be considered a best or final estimate. Further testing and refinement of the method introduced in this report is necessary. Furthermore, the estimates given here are not comparable to any earlier estimates of population size, particularly that of Rice (1960), because of the different assumptions behind that estimate. Rice's estimate is discussed later. In general, beach counts of monk seals are lower now than 25 years ago, and recent indications are that populations are still declining at most islands.

METHODS

Field procedures for making the beach counts on Lisianski Island are reported in Stone (1984) and Johanos and Kam (footnote 2). Counting procedures were the same on other islands. In this report, only the effort-standardized counts, termed "censuses" in the above references, are used. The counts are broken down by sex and age class. The number of seals whose sex could not be determined, either from morphological or behavioral characteristics or from the identifying bleach marks, was negligible at Lisianski Island except in the early counts of 1982 before all seals had been marked. At other islands, a higher fraction of seals on the beach was not in a position to be easily sexed, and these seals were assigned to sex classes in proportion to the sighting of known-sex animals. Age classes are based on size and are somewhat subjective, but a rough division into adults, subadults, juveniles, and pups of the year is possible. For each age and sex class on each date, the actual fraction of seals seen by the researchers during their surveys at Lisianski Island was computed.

Given a beach count of seals of a particular age and sex class on some other island, the total number of seals of this age and sex class can now be estimated as

$$\hat{N} = \frac{c}{f},$$

where c is the mean beach count on the island and f the mean fraction of seals of the same age and sex class present on the beach at Lisianski Island during the same time period. Using a Taylor expansion of the function (the delta method of Seber, 1982:7), the bias of this estimate is

$$b = \frac{c \text{ var}(f)}{f^3}.$$

For a reasonably precise estimate of f , this bias will be negligible, since

$$\frac{b}{\hat{N}} = \frac{\text{var}(f)}{f^2} = [\text{CV}(f)]^2,$$

where CV is the coefficient of variation. In this report, since f is a mean of many counts, its coefficient of variation is quite small, generally <0.05 . With the same method, the variance of $\hat{N}$ can be estimated as

$$\text{var}(\hat{N}) = \frac{\text{var}(c)}{f^2} + \frac{c^2 \text{var}(f)}{f^4}.$$

The variances of c and f can be estimated by considering the bidaily counts to be replicates. This is a justifiable assumption if the fraction present on the beach shows no trend during the period the counts were made. The results presented below show that for many age and sex classes, the fraction of seals hauled out seemed to show little change over several weeks or months. Within such blocks of time, therefore, the counts were considered replicates in order to estimate the variances of c and f .

RESULTS

Actual Haul-Out Fractions at Lisianski Island

The actual fractions of monk seals of various age and sex classes hauled out at Lisianski Island in 1983 are shown in Figures 1-3. The fraction of adult male seals hauled out averages about one-third and shows no distinct trends (Fig. 1A). Figure 1B shows that the fraction of adult female seals hauled out is somewhat higher overall than the fraction of adult males hauled out during this same period. This is due largely to some females nursing pups. When only the non-nursing adult females are considered, the fraction hauled out is close to the figure for adult males. The fraction of subadult males present on the beach appears rather variable through the month of May, but then shows less variability through early August (Fig. 2A). The fraction of subadult females hauled out increases at first and then decreases, probably due to molting (Fig. 2B). The fractions of juvenile males (Fig. 3A) and females (Fig. 3B) present on the beach showed no distinct trends during the same late April-early August period.

The means, variances, and covariances of the daily haul-out fractions for each of these age and sex classes at Lisianski Island are given in Table 1. Generally speaking, one-half to one-third of all age and sex classes present around Lisianski Island would be expected to be counted during one of the early afternoon surveys. Put another way, the total number of seals is two to three times the number counted on the beach.

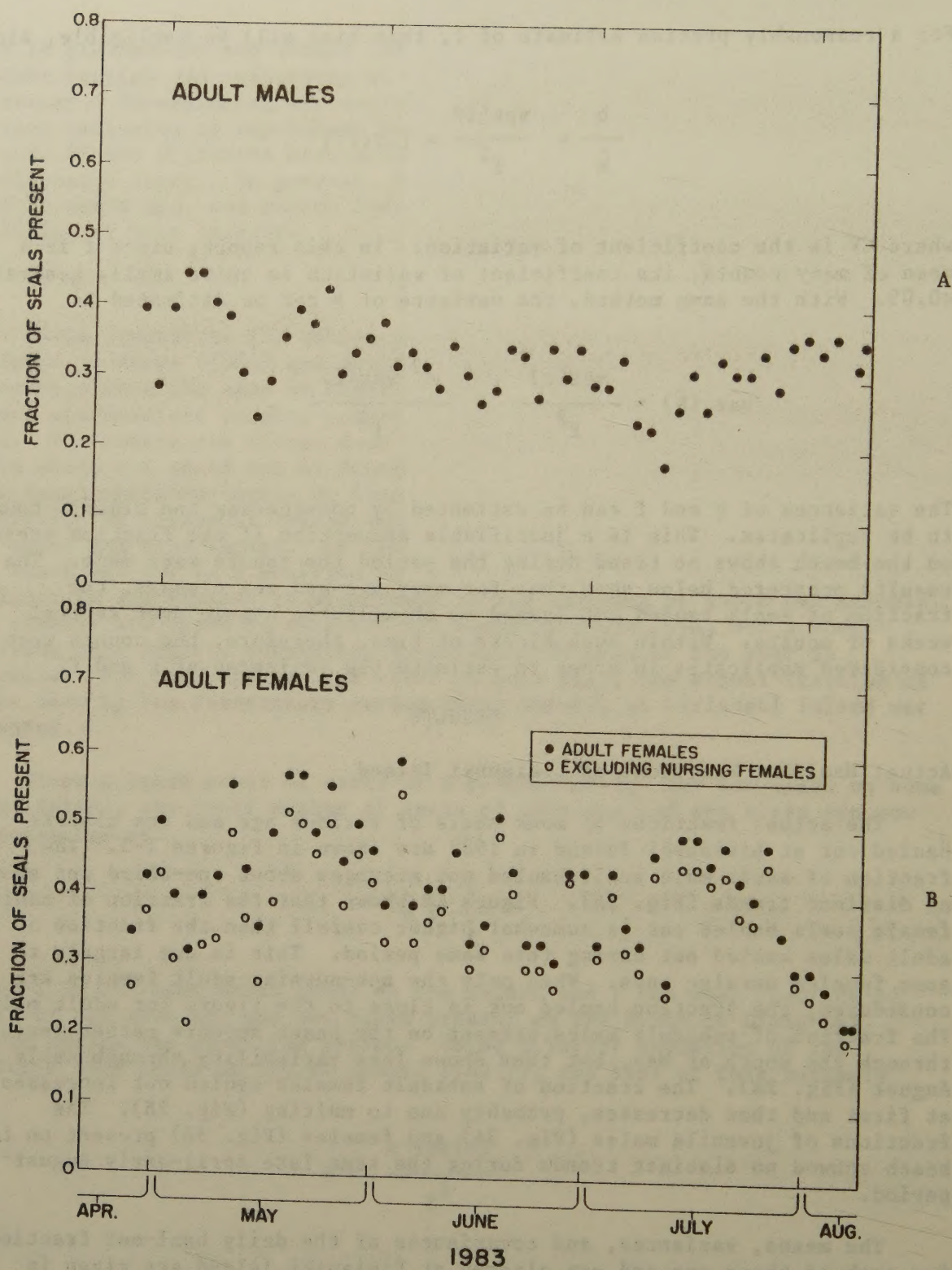


Figure 1.--Fractions of adult male (A) and female (B) monk seals hauled out at Lisianski Island, 1983.

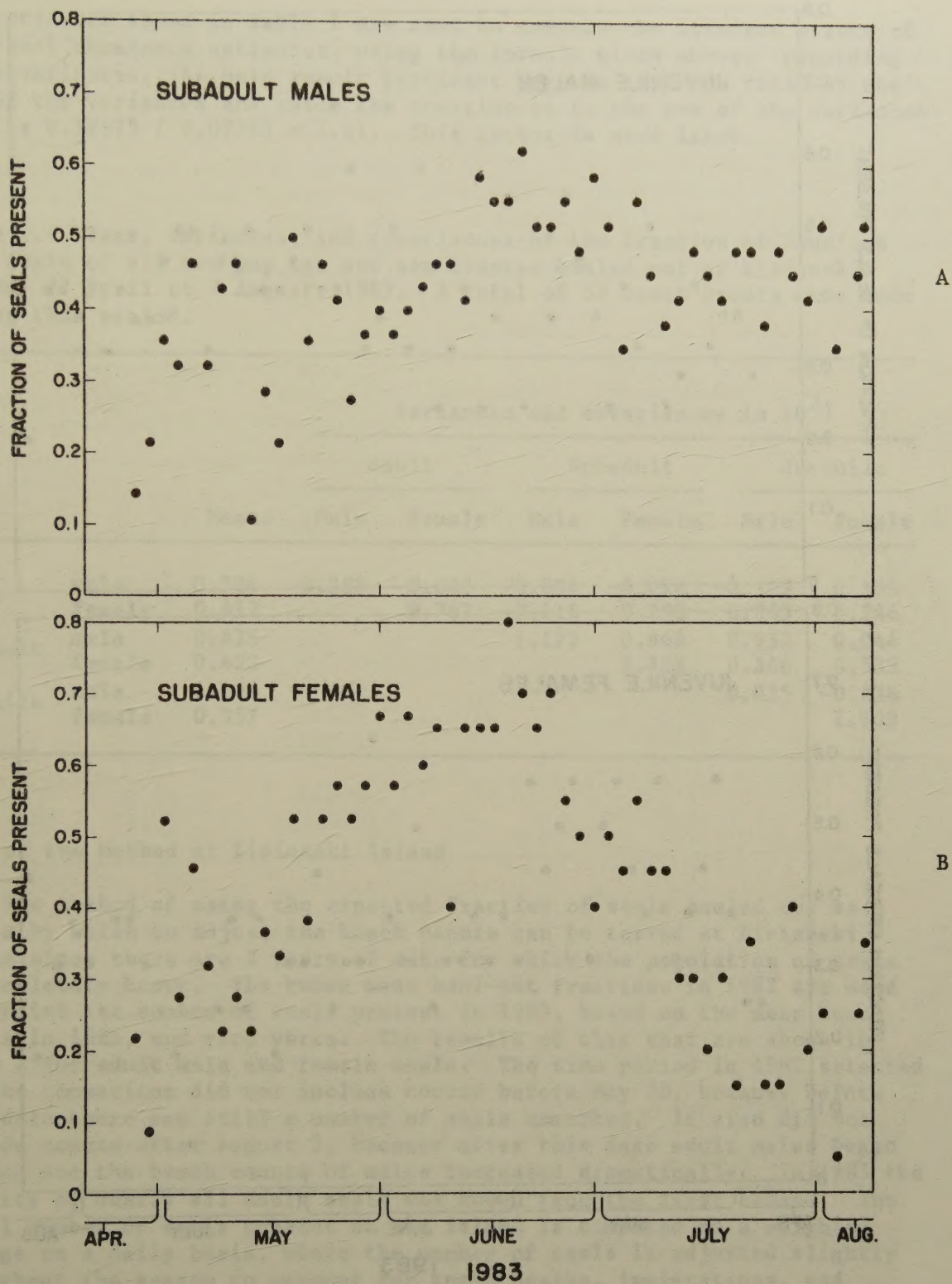


Figure 2.--Fractions of subadult male (A) and female (B) monk seals hauled out at Lisianski Island, 1983.

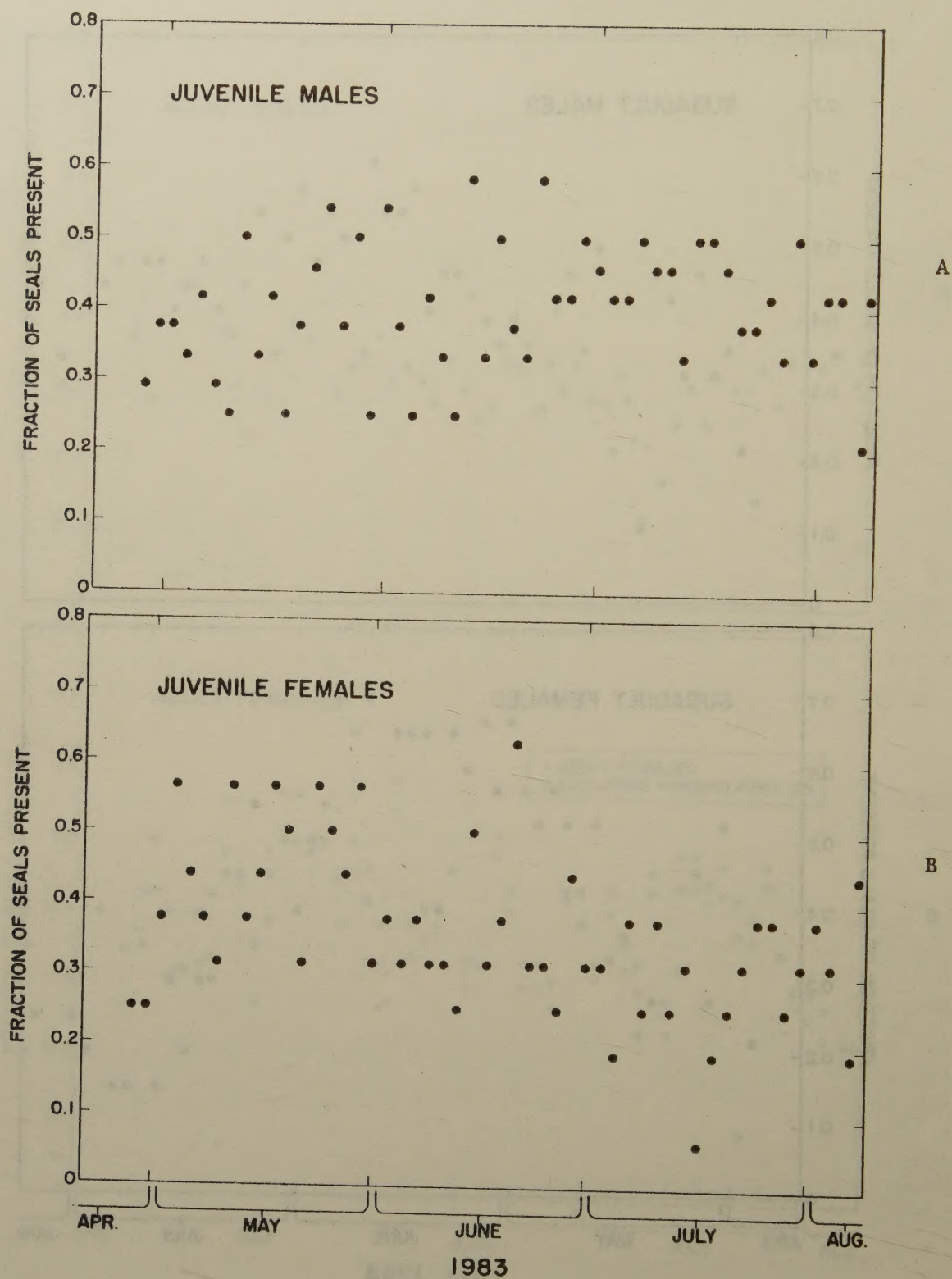


Figure 3.--Fractions of adult male (A) and female (B) monk seals hauled out at Lisianski Island, 1983.

The variances shown in Table 1 are used to compute the standard errors of monk seal abundance estimates, using the formula given above. Regarding the covariances, the main result pertinent here is that the ratio of the sum of the variances and twice the covariances to the sum of the variances only is $0.12525 / 0.07783 = 1.61$. This factor is used later.

Table 1.--Means, variances, and covariances of the fraction of Hawaiian monk seals of all non-pup age and sex classes hauled out at Lisianski Island, 27 April to 7 August, 1983. A total of 52 beach counts were made during this period.

		Variances and covariances (x 10 ²)						
			Adult		Subadult		Juvenile	
		Means	Male	Female	Male	Female	Male	Female
Adult	male	0.326	0.288	0.042	-0.084	-0.046	-0.102	0.188
	female	0.412		0.767	-0.116	0.293	0.043	0.246
Subadult	male	0.426			1.172	0.848	0.252	0.044
	female	0.423				3.408	0.366	0.533
Juvenile	male	0.401					0.825	-0.136
	female	0.357						1.323

Test of the Method at Lisianski Island

The method of using the expected fraction of seals hauled out as a factor by which to adjust the beach counts can be tested at Lisianski Island since there are 2 years of data for which the population of seals is completely known. The known mean haul-out fractions in 1982 are used to predict the number of seals present in 1983, based on the mean beach counts in 1983, and vice versa. The results of this test are shown in Table 2 for adult male and female seals. The time period in 1982 selected for the comparison did not include counts before May 30, because before this date there was still a number of seals unmarked. It also did not include counts after August 3, because after this date adult males began molting and the beach counts of males increased dramatically. In 1983 the identity of nearly all adult seals was known from the first census. The actual number of seals present on the island is computed as a weighted average on a daily basis, where the number of seals is adjusted slightly throughout the season to account for known deaths, immigrations, and emigrations.

Table 2.--Comparison of the actual number of adult monk seals present on Lisianski Island in 1982 and 1983 with the estimated number based on the beach counts (c) and the fraction of seals present on the beach (f). For each year, the estimated number of seals is computed using the beach counts of that year and the fraction present from the other year. The standard error (SE) of the estimate is computed from the standard deviations (SD) of c and f by a formula given in the text. The actual number of seals shown here is a daily mean of the number of seals present during the period indicated. The estimated number of male and female adult seals in each year is close to the known actual number, less than one standard error in all cases.

Dates	Sex	c = average adult beach count (SD)	No. of counts	f = average fraction present (SD)	Estimated $\hat{N} = c/f$ (SE)	Actual N
30 May- 3 Aug. 1982	M	31.81 (6.02)	32	0.319 (0.0608)	97.6 (4.0)	99.7
	F	16.63 (3.74)	32	0.413 (0.0951)	40.4 (2.0)	40.2
27 Apr.- 7 Aug. 1983	M	32.35 (5.29)	52	0.326 (0.0537)	101.4 (4.1)	99.2
	F	15.92 (3.25)	52	0.412 (0.0875)	38.5 (1.9)	38.7

The estimated number of seals based on the beach counts is in all cases close to the known actual number of seals (Table 2). The standard error of the estimate is small because of the large number of replicate counts. The estimated number of seals is less than one standard error from the known number for both sexes and both years. The haul-out pattern between years is very consistent. In 1982 an average of 31.9% of the adult males were hauled out during this period, while in 1983 the figure was 32.6%. The adult female fractions, including nursing females, were 41.3% in 1982 and 41.2% in 1983. These results indicate that the known haul-out fractions at Lisianski Island can be used to adjust beach counts to obtain estimates of the total population size.

Application to Other Islands

In Table 3 this method is applied to the 1983 beach counts at other islands and atolls in the Northwestern Hawaiian Islands. The beach counts on which these estimates are based are taken from unpublished data of the monk seal program. Separate estimates of the number of males and females in each of three age classes (adult, subadult, and juvenile) are shown at

Table 3.--Estimated numbers of Hawaiian monk seals in the summer of 1983 at six major islands or atolls in the Northwestern Hawaiian Islands. Abbreviations are: A = adult, S = subadult, J = juvenile, M = male, F = female, SE = standard error. The estimates of abundance and their standard errors are computed from beach counts by methods explained in the text.

Island or atoll	Dates of 1983 counts	No. of counts	Estimated No. of seals in each age/sex class (with SE)							Nonpups total (SE)	Total (SE)
			AM	AF	SM	SP	JM	JF	Pups		
Lisianski	4/27-8/7	52	99*	39*	29*	21*	24*	16*	25*	228*	253*
Necker	7/28-8/5	5	36 (4.0)	19 (1.8)	4 (1.2)	5 (1.6)	5 (1.7)	1 (0.6)	3*	70 (6.5)	73 (6.5)
Laysan	4/24-7/21	24	90 (3.8)	49 (2.3)	23 (2.0)	29 (2.4)	22 (1.2)	26 (1.8)	24*	239 (7.4)	263 (7.4)
Kure	4/22-6/28	31	28 (1.4)	7 (0.5)	6 (0.8)	4 (0.4)	5 (0.5)	7 (0.7)	3*	57 (2.5)	60 (2.5)
Pearl and Hermes Reef	5/30-7/14	8	22 (2.4)	24 (1.9)	8 (1.7)	7 (0.8)	13 (1.0)	9 (1.8)	12*	83 (5.2)	95 (5.2)
French Frigate Shoals:			127 (11.7)	188 (11.6)	81 (11.5)	116 (15.0)	73 (8.6)	63 (6.5)	96** (1.0)	648 (34.7)	744 (34.7)
Tern	4/17-5/31	19	44 (2.8)	15 (1.0)	24 (2.6)	28 (3.7)	15 (1.5)	15 (1.7)	0*	141 (7.4)	
East	4/19-8/3	35	3 (0.5)	49 (2.5)	3 (0.3)	5 (0.6)	2 (0.4)	2 (0.4)	46*	64 (3.5)	
Whale-Skate	4/19-8/2	35	16 (1.2)	47 (2.7)	11 (1.0)	11 (1.2)	9 (0.8)	8 (1.0)	31*	102 (4.5)	
Trig	4/28-8/1	14	13 (2.0)	14 (1.3)	5 (1.0)	3 (0.4)	2 (0.3)	5 (0.7)	1*	42 (3.5)	
Shark	5/8	1	11 (4.6)	4 (2.4)	12 (6.0)	3 (1.6)	5 (2.5)	3 (1.4)	0*	38 (10.9)	
Disappearing	4/23	1	21 (9.2)	27 (9.7)	22 (9.2)	54 (13.7)	31 (7.5)	24 (5.7)	1*	179 (29.4)	
Gin and Little Gin	7/26	1	8 (3.1)	6 (2.4)	2 (1.1)	8 (4.2)	5 (2.5)	0	1*	29 (8.1)	
Bare	4/26-6/5	2	7 (2.2)	3 (1.7)	1 (1.1)	2 (1.1)	2 (1.3)	2 (1.5)	0*	17 (4.7)	
Round	4/26-6/9	4	3 (1.5)	15 (2.7)	0	0	1 (0.5)	1 (0.5)	9*	20 (4.0)	
Mullet	4/16-7/9	7	1 (0.4)	8 (1.7)	1 (0.4)	2 (0.5)	1 (0.4)	3 (0.5)	5*	16 (2.5)	
Totals			402 (13.2)	326 (12.1)	151 (11.9)	182 (15.3)	142 (8.9)	122 (7.0)	163 (1.0)	1,325 (36.4)	1,488 (36.4)

*Known (not estimated) quantity.

**Total greater than sum by islands because the birth locations of some pups were unknown.

each island or atoll group, rounded off to the nearest whole number. Standard errors for all estimates are also given, calculated from the formula given above. Standard errors for totals on each island are computed by adding the variances of the separate estimates and multiplying by 1.61 to account for the covariances. At each island the number of pups born in 1983 is known since pups of the year remain recognizable for many months. However, the pup production figures should be considered minimum estimates since a few pups may have been born and died before the arrival of the researchers in April. Births after August would also be missed, but these are expected to be very few, if any.

The estimated total number of Hawaiian monk seals alive during the summer of 1983, other than pups, is 1,325 (Table 3). Since 163 pups were born in 1983, the total number of seals is estimated to be 1,488, with a 95% confidence interval from 1,417 to 1,559. Half the total population is at French Frigate Shoals, and over half the births occurred there. Almost a third of the total number of births in 1983 occurred at a single island, East Island at French Frigate Shoals. This confirms earlier impressions of the importance of this atoll for the monk seal population.

As has been recognized for several years, there is an excess of adult males over adult females at Kure Atoll and at Lisianski, Laysan, and Necker Islands. This imbalance is thought to be a cause of aberrant behavior by adult males and is currently the focus of research by the Marine Mammals and Endangered Species Program of the Honolulu Laboratory. At Pearl and Hermes Reef the numbers of adult males and females are approximately equal, while at French Frigate Shoals there appear to be more females than males. Overall, the total number of adult males is estimated to be 402 and the number of adult females 326.

DISCUSSION

With the exception of the estimates of Johnson and Johnson (1981), based on several years on their intensive study at Laysan Island, it has not been possible in the past to relate the number of monk seals counted during a survey to the total population resident around an island. Because of the complete censusing of the monk seal population at Lisianski Island during 1982 and 1983, however, it will now be possible to estimate the total population at Lisianski quite precisely in the future simply from a series of beach counts. This assumes, of course, that future counts are taken in a similar way and that the haul-out behavior of the seals at Lisianski does not change. The similarity of haul-out fractions at Lisianski from 1982 and 1983 (Table 2) suggests that they do not vary much from year to year.

To extend the results from Lisianski Island to other islands, it is necessary to make the further assumption that the fraction of seals hauled out is the same on all islands. The total 1983 population of monk seals is estimated, under this assumption, to be 1,488, with a 95% confidence interval from 1,417 to 1,559 (Table 3). The assumption that not only the haul-out fraction but the variance of the haul-out fraction does not depend

on island topography, seal density, sex ratio, island size, and other factors is a strong one. Since the validity of this assumption is clearly central to placing any confidence in the abundance estimates in Table 3, it is recommended that data be gathered in the future to test it. During the 1984 field season, a complete enumeration of the population at Laysan Island is expected, and it will then be possible to compare the haul-out fractions at Laysan with those previously determined at Lisianski.

The monk seal population estimates in Table 3, however, do seem to be reasonable based on other information, and this is a partial validation of the assumption of equal haul-out behavior. For example, the estimates in Table 3 are derived solely from beach counts and do not depend at all on the considerable effort which has gone into the individual identification of seals at most of the islands. At some islands, it is felt that all or a substantial proportion of certain age and sex classes is recognizable. At Laysan Island, for example, the number of adult females in 1983 was 48 or 49 (Alcorn³), identical to the estimate of 49 in Table 3. Such close agreement gives some confidence that the key assumption that the average fraction of seals hauled out on a beach does not vary between Lisianski and other islands is at least approximately true.

Monk seals move among islands and atolls, although the rate of interatoll movement appears to be low (Johnson and Kridler 1983). Interatoll movement of the seals will not affect the estimates of abundance presented in this report, however, since an equal number of seals is expected, on average, to immigrate to and emigrate from any particular island. Even if there is a net migration from one island to another, the estimates given here will not be affected since all beach counts were made in 1 year and at the same time of year. A bias in the estimated total abundance could result if, for example, a summer estimate at one island were added to a fall estimate at another island and there was a net migration of seals between the two islands during that period. A similar bias could result by adding estimates from several islands in different years. There is some evidence of a population shift from west to east over the past 25 years (Johnson et al. 1982).

The precision of the estimates of population size depends largely on the number of available beach counts. Since the fraction of seals present on any one beach count can be quite variable (cf. Figs. 1-3), replicate beach counts are needed to compute an average number of seals present. The number of beach counts available in 1983 varies widely by island, from 52 at Lisianski Island to single counts at some of the islands at French Frigate Shoals. Most of the islands at which there is a low number of counts have only a few seals, but one, Disappearing Island at French Frigate Shoals, had a beach count which projects to more than 10% of the total monk seal population. Because only a single count was made at this island in 1983, the standard error of the estimated number of seals is

³D. Alcorn. Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812, pers. commun., June 1984.

large. In fact the variance from this one island contributed two-thirds of the variance of the estimate for the entire population (compare the standard error at Disappearing Island, 29.4, with the standard error of the total population estimate, 36.4). The precision of the total population estimate could be greatly increased by a few replicate counts, from Disappearing Island in particular. It is recommended that, in the future, more counts be attempted at this island.

The total 1983 population estimate of 1,488 is a preliminary estimate subject to further analysis of these and other data. Comparison of present beach counts with those in the past is difficult because past counts were made using different procedures (Johnson et al. 1982). Rice (1960) reported the highest count from a combination of aerial and ground surveys of all the major islands and atolls in 1957-58. For comparison with these earlier counts, Johnson et al. (1982) also reported the highest count from each island for each year in the period 1976-78 and, despite the variability introduced by different methods of counting, these authors found significant trends in population size at all islands for the period 1957-78. Monk seal populations decreased at the western end of the chain (Kure, Midway, Pearl and Hermes, Laysan, and Lisianski) and increased at the eastern end of the chain (French Frigate Shoals and Necker).

Based on the greater information we now have on the monk seal's haul-out behavior, a more detailed comparison of past and present counts will be made in the future. However, because Rice (1960) considered his estimate of 1,350 seals to be a total population estimate rather than simply a highest beach count, and this figure has been mistakenly cited as a total population size for monk seals at that time (1957-58), a further discussion of this particular estimate is merited here.

Rice (1960) considered that because the "counts at each atoll approach a fairly consistent maximum...the counts, therefore, are not appreciably below the actual population." The consistency of any counts, however, does not imply anything about what fraction of the population they represent. Furthermore, Figures 1-3 make it clear that, depending on the time of year and number of counts, the highest of several beach counts would be about 50-60% of the total number of seals. Rice had fewer counts at each island than the number of counts plotted in Figures 1-3, and the chance of getting a single very high count is correspondingly lower. Rice did add 150 (about 15% of his highest beach counts) to adjust for seals missed, but this is now seen to be an undercompensation. For these reasons, therefore, Rice's population estimate of 1,350 seals is undoubtedly low for that time.

Present beach counts of monk seals, excluding pups, are around 500 animals, considerably below Rice's counts. Whatever the details of different counting methods, the general picture for the Hawaiian monk seal continues to be that the population has suffered a serious decline since the late 1950's and is in need of strict protection. The small total population which these beach counts indicate, as reported here, is further cause for concern.

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